65-145 GHz InP MMIC HEMT Medium Power Amplifiers

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***Abstract* — In this paper, we present two MMIC power amplifier designs utilizing InP HEMT technology. The first amplifier covers two full waveguide bands, WR10 (75-110 GHz) and WR8 (90-140 GHz), yielding a maximum output power of at least 20 mW to 40 mW between 65-140 GHz. The second design is optimized for the WR10 waveguide band and provides at least 13 dB of large signal gain over 75-110 GHz, and an output power of 16.5 +/- 0.5 dBm (40-50 mW).**

I. INTRODUCTION

There is an increasing need for power sources in the 100 GHz range and above. Such sources could consist of active or passive doublers or triplers driven by commercial synthesizers up to 26 GHz. The output power of the multipliers is usually quite small, and requires amplification for practical use. In this paper, two amplifiers are presented which provide high gain, 20-50 mW of output power, and large bandwidth. The first amplifier covers two full waveguide bands: WR10 (75-110 GHz), and WR8 (90-140 GHz). The second amplifier was optimized for the highest gain and power in only the WR10 waveguide band. Such amplifiers could find wide usage in test equipment, as laboratory sources, for local oscillator sources in heterodyne receivers, and in next generation fiber optic communications.

Previous amplifier designs have demonstrated full WR10 waveguide bandwidth, with 6 dB large signal gain and output power of at least 25 mW. [1]. Other amplifiers in this frequency range achieve higher output power and very good power added efficiency of 18% over a narrow range of bandwidth[2]. The highest power amplifiers in the 100 GHz frequency range have demonstrated very high power 23-26 dBm over approximately 10-15 % bandwidth[3,4]. We now present the results of a medium power ampifiier covering two full waveguide bands up to 145 GHz, and an optimized power amp for the WR10 waveguide band.

I. DEVICE FABRICATION AND CIRCUIT DESIGN

The circuits we will discuss have been fabricated at HRL Laboratories, using a 0.1micron InGaAs/InAlAs/ InP high electron mobility transistor (HEMT) process. This same process has been used to fabricate wide band low-noise amplifiers as high as 205 GHz[5]. The amplifiers were fabricated on a 3" wafer, which was then thinned to 50 μm. The process also includes a wet etched backside via holes for parallel plate mode suppression.

The HEMT device model was developed using DC and pulsed IV and multi-bias S-parameter measurements from 1-40 GHz. The small signal equivalent circuit parameters were extracted using the cold/hot FET method for each biasing point. Angelov's model was used to predict output power [6].

Both amplifiers make use of grounded co-planar waveguide topology (CPWG). The first amplifier, referred to as PA1, employed three stages. The first two stages used HEMTS having 4 gate fingers 37 microns wide, the the third stage combined two 4x37 HEMTs in parallel. The total device periphery in the output stage is 300 μm. Fig. 1 shows a photograph of the fabricated MMIC power amplifier. The chip size is 1.2×1.4 mm^2.

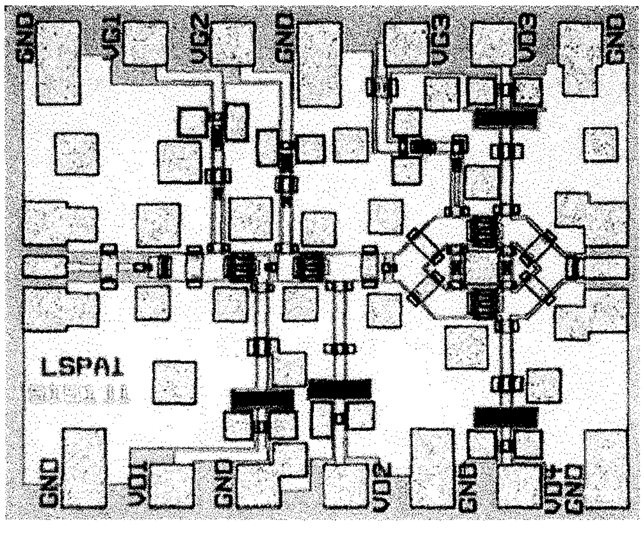

Figure 1. Chip photograph for medium power amplifier having at least 9 dB of gain from 65-145 GHz, spanning two full waveguide bands.

III. MEASUREMENTS

Small signal S-parameters of the amplifier chip PA1 were obtained using an HP 8510A vector network analyzer, with OML frequency extenders separately covering three waveguide bands: WR10 (65-110 GHz), WR8 (90-140 GHz), and WR5 (140-220 GHz). All of the data were obtained via on-wafer measurements, using GGB Industries waveguide-to-cpw wafer probes for the RF input and output. The waveguide wafer probes were also designed for the three separate waveguide bands. DC power was also applied to the chips using wafer probes for gate and drain bias.

In addition to the simulation data, Figure 2 also illustrates the measured S-parameters taken in the three waveguide bands. Very good agreement between measured and modeled data is shown. The amplifier exhibits 9 dB gain or more from 65 to 145 GHz, having 80 GHz of bandwidth. The glitch apparent around 143 GHz is a product of the measurement system, and is not expected to be a result of the amplifier chip itself (based on other measured data obtained with this system). Data obtained in the WR5 waveguide band appear noisier than the lower frequency bands, presumably due to the weaker signal level of the multiplier source in the frequency extender at these higher frequencies. The small signal data were obtained for a drain voltage Vd=2V, and a total drain current Id = 220 mA. The gate voltages were optimized for maximum gain and bandwidth, and varied between 0 and +0.1 V.

Power measurements for PA1 were first obtained in the WR8 waveguide band using a tunable 106-140 GHz Carlstrom Gunn oscillator as the RF source. A variable attenuator was placed after the Gunn, and a WR8 GGB probe was attached to the input of the chip. The output of the chip was attached to a similar WR8 probe, which was then fed to a WR8 Anritsu power meter. The input and output power levels entering and leaving the power amplifier chip were corrected for the loss of the GGB wafer probes. For the power measurements, the drain voltage was increased to Vd =2.6 V, and Id was increased to 250 mA. The gate voltages were $Vg1$=0V, and $Vg2$ = $Vg3$=+0.2V.

The output power as a function of frequency, measured in WR8, is shown in Figure 3. At least 25 mW (14 dBm) is obtained from 106-140 GHz. The input power was kept at approximately 8 dBm, except at 140 GHz, where the Gunn oscillator source only yielded 6 dBm at the input to the chip.

Output power as a function of input power was also obtained using the same configuration, on-wafer, for

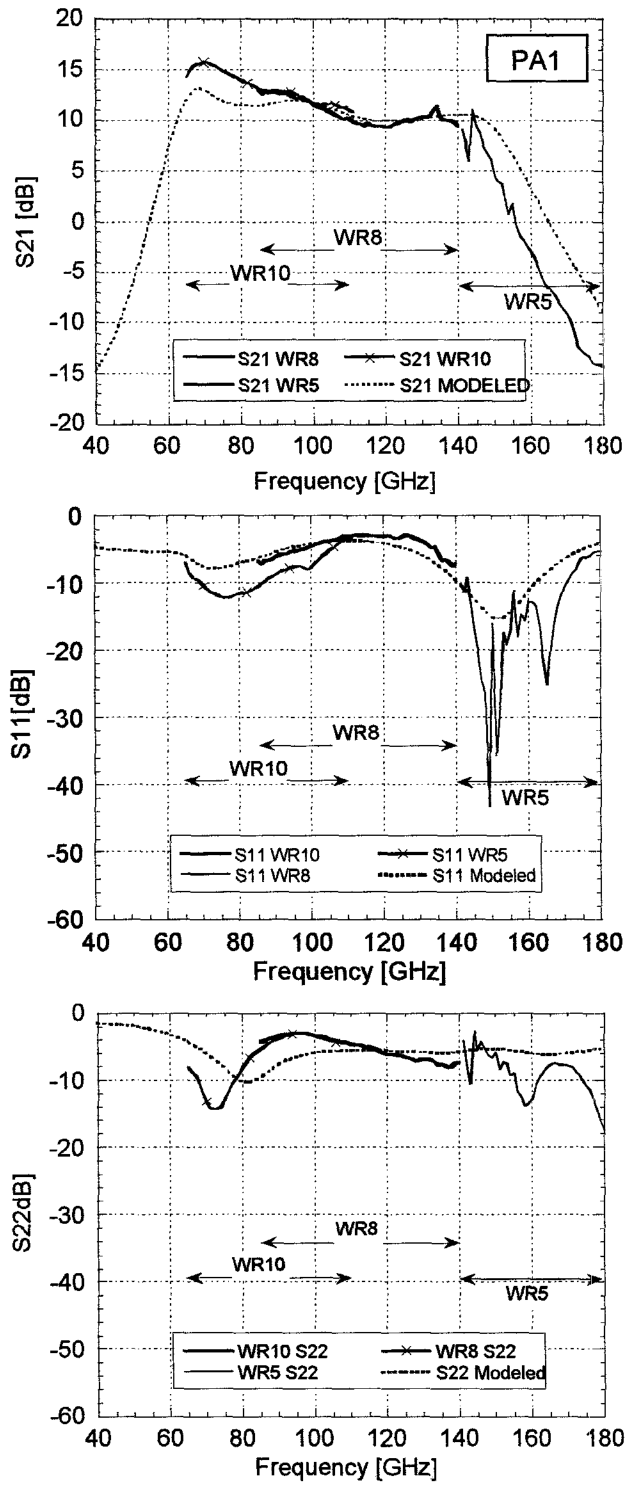

Fig. 2. S-parameters measured in three separate waveguide bands for the wide band power amplifier PA1. The top graph illustrates the measured and simulated S21 as a function of frequency. Middle graph: Modeled and measured S11. Bottom graph: Modeled and measured S22.

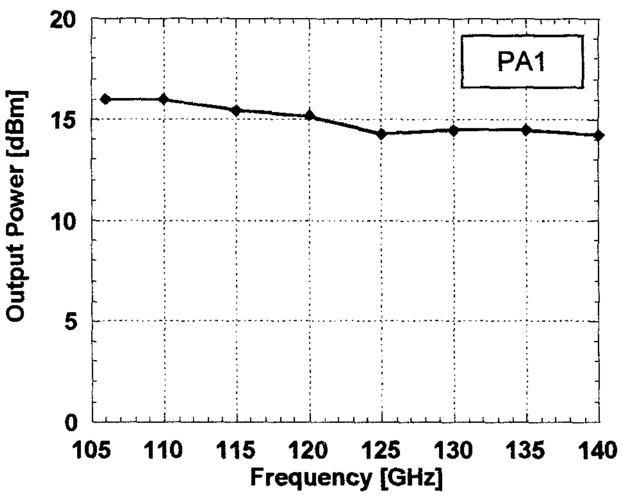

Figure 3. Output power as a function of frequency for chip PA1, measured using 8dBm input power, except at 140 GHz, where only 6 dBm of input power was available.

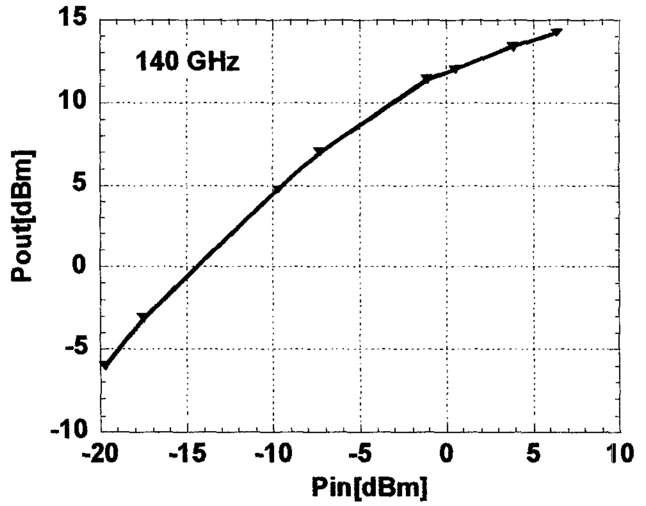

Figure 4. Output power as a function of input power for PA1, measured using a WR8 Anritsu power meter at 140 GHz.

several different frequencies. Figure 4 shows the Pout vs Pin results at 140 GHz. At low power levels, the gain is nearly 14 dB, due to the increased Vd=2.6Vand Id=250 mA, as compared to the small signal data obtained for Vd=2V, Id=220 mA (shown in Figure 2). At high power levels, the power gain is compressed to 8 dB, for a maximum output power of 14 dBm (25 mW) at 140 GHz.

We have also measured the output power from PA1 in the WR10 waveguide band, from 65-115 GHz. The measurement configuration consisted of a backward wave oscillator (BWO), followed by a variable attenuator, a directional coupler to capture the input power measurement, and a WR10 GGB wafer probe at the input to the chip. The output of the chip was fed into another WR10 GGB wafer probe, and then into an HP power meter equipped with W-band sensor. The data were calibrated between 75-110 GHz only; no calibration factor was obtained for data above 110 GHz or below 75 GHz.

For the WR10 power measurement, we used the same PA1 chip, fabricated from a second wafer which exhibited slightly higher small signal gain than the first wafer. Figure 5 shows the output power data as a function of frequency for four different input power levels: -4 dBm, OdBm, 5 dBm, and 8 dBm. The peak output power occurs at 79 GHz, and yields 36 mW (15.6 dBm). At least 20 mW (13 dBm) of output power is obtained across 65-115 GHz.

The power-added efficiency is between 2 - 4% across 80 GHz of bandwidth. Clearly, the maximum power, gain, efficiency, and return losses could be optimized over a smaller bandwidth. In the next section, we describe a similar amplifier, referred to as PA2, which was optimized for full 75-110 GHz performance.

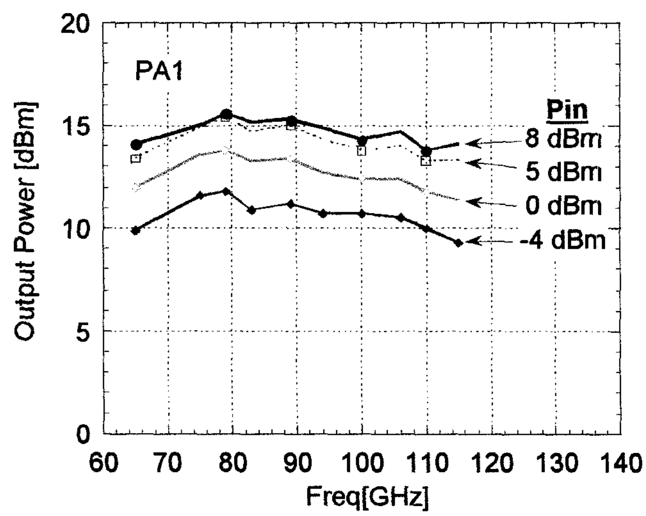

Figure 5. Output power as a function of frequency and input power, from a second wafer of chips which yielded higher gain for the same chip design. At right, the input power for each curve is indicated.

III. POWER AMPLIFIER OPTIMIZED FOR W-BAND

A second power amplifier was designed, based on PA1, which was optimized for maximum gain and output power from 75-110 GHz. Such an amplifier could find wide applications in test equipment. The PA2 chip utilizes the same InP HEMT process at HRL. Figure 6 shows the output power as a function of frequency from the PA2 chip. The measurement was again performed on wafer using a BWO as the W-band source. The input power was fixed at 3 dBm (2 mW). We observe a large

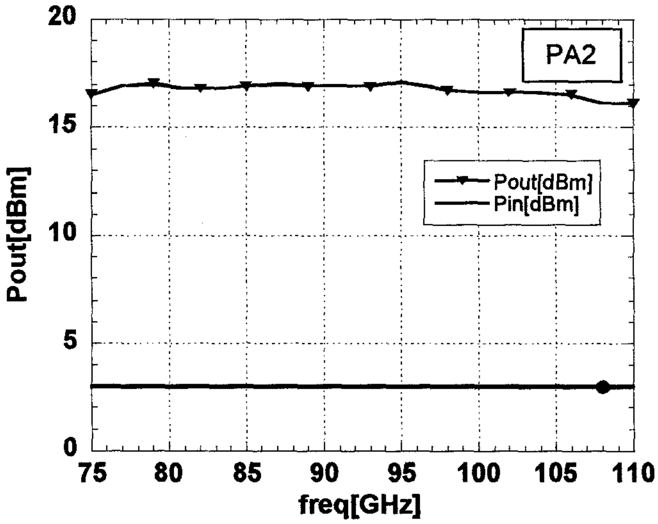

Figure 6. Output power vs frequency for the optimized PA2 power amplifier, for a fixed input power of 3 dBm (2 mW).

signal gain of 13 dB, and an output power of 16.5 +/- 0.5 dBm (40-50 mW). For the measurement, *Vd*=2.5V, *Id*=250 mA, and *Vg* = 0. The PA2 design exhibits a minimum power-added efficiency of 6%. To date, this is the highest power, highest large signal gain full-waveguide band WR10 MMIC amplifier found in the literature.

V. Conclusion

We have presented results of MMIC power amplifiers which cover not only one full waveguide band (WR10), but two full waveguide bands (WR10 and WR8). The two-waveguide band amplifier exhibits at least 20-40 mW of output power from 65-140 GHz, while the WR10 waveguide-band amplifier exhibits 40-50 mW of output power from 75-110 GHz. InP HEMTs show great promise as practical, wide-band power amplifiers, and it is anticipated that the results can be scaled to even higher frequencies in the future.

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